④

GL-TR-90-0027

AD-A223 229

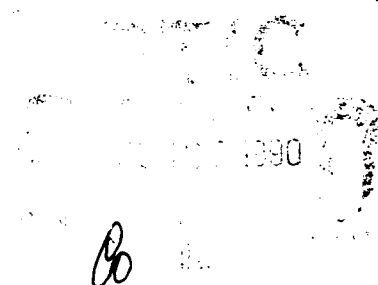Electrodynamics of the High Latitude Ionosphere

R. A. Heelis

University of Texas at Dallas
Center for Space Sciences
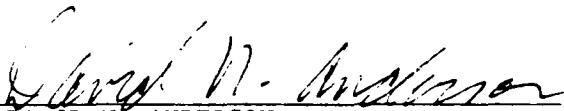P. O. Box 830688
Richardson, TX 75083-0688

February 1990

Final Report
September 1986–September 1989

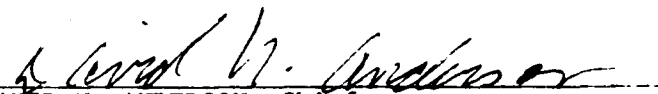APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731-5000

90 06 25 168

"This technical report has been reviewed and is approved for publication"

DAVID N. ANDERSON
Contract Manager

DAVID N. ANDERSON, Chief
Ionospheric Modelling & Remote Sensing Branch
Ionospheric Physics Division

FOR THE COMMANDER

ROBERT A. SKRIVANEK, Director
Ionospheric Physics Division

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 1990	Final Report Sept. 1986 – Sept. 1989

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Electrodynamics of the High Latitude Ionosphere	PE: 61102F PR 2310 TAG9 WUAD
6. AUTHOR(S) R. A. Heelis	Contract F19628-86-K-0042

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
University of Texas at Dallas Center for Space Sciences P. O. Box 830688 Richardson, TX 75083-0688	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Geophysics Laboratory Hanscom AFG, Massachusetts 01731-5000 Contract Manager: David Anderson/LIM	GL-TR-90-0027

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for public release; distribution unlimited	

13. ABSTRACT (Maximum 200 words)

Both large and small scale structure in the plasma density and velocity are important phenomena to be understood in the ionosphere. The ability to characterize the high-latitude plasma motion over large spatial scales is demonstrated here with the development of a model that can be driven by data inputs. The model can also be used to study the mechanisms producing large scale structures in the plasma. The applicability of the model is demonstrated for periods when the interplanetary magnetic field has a southward component. During periods of northward IMF the electrodynamics of the ionosphere on spatial scales of 100 km must be understood. Here the combination of ground based and space based data are invaluable tools. We show that mesoscale features may be coherent over many hours and constitute an important signature of the interaction of the Earth's magnetic field with the interplanetary medium.

14. SUBJECT TERMS		15. NUMBER OF PAGES
Ionosphere, Plasma, Electric Fields		34
		16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

CONTENTS

Accession For

DTIC
COPY
INSPECTED
6

A-1

ELECTRODYNAMICS OF THE HIGH LATITUDE IONOSPHERE

1. Introduction.

The study of high latitude ionospheric electrodynamics is important to both our understanding of the ionospheric plasma and to an understanding of the interaction between the Earth's magnetic field with the interplanetary medium. A quantitative description of the convective motion of the high latitude ionospheric plasma is being pursued for the purpose of studying plasma structures where the convective history of the plasma may be important. The model developed for describing conditions during southward interplanetary magnetic field (IMF) has been adapted to possess a flexibility allowing some representations of convection patterns that may exist during times of northward IMF. Of particular interest during times of northward IMF is the electric field configuration associated with stable auroral features at very high latitudes. The electrodynamic configuration of these features has been described using a variety of satellite and ground based diagnostics that may also help us to understand the global configuration of the magnetic and the electric field associated with them.

The dominance of small-scale structure in the electric field and plasma density during times of northward IMF has lead to a study of the ways in which these parameters are coupled. While it is customary to think of the Earth's magnetic field lines as electric equipotentials, it can be shown that they are far from exhibiting this property for scale sizes less than a few kilometers. The effects that scale-size dependent electric field mapping has on the development of plasma structure has been investigated in some detail. Large and small scale electric fields in the ionosphere drive horizontal currents that are ohmically dissipated as heat in the altitude region below about 250 km.. Above this altitude significant frictional heating of the ions can occur as a result of a relative drift between the ions and the neutral gas. We have studied the differences between representations of this heating in terms of a height-integrated Joule heating rate and an in-situ frictional heating rate. It can be quite clearly seen that the heating rate per particle must be considered in each region of interest in order to relate measurements made in one region to conditions existing in another.

The research activities reported on here, represent some significant advances in our understanding of physical processes in the high latitude ionosphere. They also provide some tools with which the phenomena can be modelled and represented. The work described

here has significant implications for future efforts and points to the need to consider, not only the high latitude region but also the degree to which the electrodynamics is coupled to low and mid-latitudes.

2. Ionospheric Electrodynamics.

Here we describe the results of studies of large-scale (> 50 km.) electric fields in the ionosphere from a source, or sources, in the outer magnetosphere. We attempt to describe the configuration of these fields in the ionosphere, their dependence on the orientation of the IMF, and the magnetic and electric field configuration in the magnetosphere with which they may be consistent. In addition to externally applied electric fields, we also consider the internal generation of much smaller-scale electric fields produced by plasma structures. In this case, the process of electrical coupling between different regions of the ionosphere must be considered in some detail, since the magnetic field lines may not be regarded as electric equipotentials.

2.1. A model of the High Latitude Convection Pattern.

Many studies of the high latitude convection pattern have shown that temporal changes in the configuration of the pattern and the magnitude of the electric potential are extremely important considerations (Lockwood and Cowley, 1988). While measurements of the convective properties may be dominated by these effects the desire to be able to instantaneously describe the convective motion of the plasma still exists from the point of view of determining the effects of convective history on the compostion and total concentration of the ionospheric plasma. Ultimately we would like to determine all the parameters affecting the configuration of the high latitude convection pattern and specify a model, dependent on these parameters. While we are not yet in this position, we have advanced to a stage where analytical expressions can be used to represent the large scale properties of the convection pattern for southward IMF. These expressions allow convective cells of different geometries to be constructed and can therefore simulate the major features of an IMF B_y dependence for the case when the IMF has a southward component and distorted two-cell convection patterns when the IMF has a northward component. In addition to developing the mathematical expressions themselves, we have also examined our capability to reproduce a given satellite observation. In this area we have studied the high latitude potential distribution obtained from specifying only the potential distribution around the convection reversal boundary, and the shape of the boundary. Specific developments are summarized below.

2.1.1. Southward IMF

When the IMF has a southward component the high latitude ionospheric convection pattern is characterized two counter-rotating vortices producing antisunward convection at highest latitudes and sunward convection at lower latitudes. A representation of the convective motion of the plasma is obtained by illustrating lines of constant electric potential, along which, in steady state, the plasma must flow. The major attributes of these electric potential streamlines that make up the convection cells are their geometrical size and shape and the absolute value of the potential extrema that is represented by them. We have found that the convection pattern can be characterized very broadly by a circular region inside which the plasma flow is antisunward and beyond which the magnitude of the potential decreases with latitude. A quantitative description of the convection pattern can be obtained by specifying the local time distribution of the potential around the boundary of the circular region and the latitude distribution of the potential along a local time meridian. We will call the boundary of the circular region, the convection reversal boundary. Figure 1 shows a representation of the convection pattern derived from the information given above. Lines of constant potential are shown to represent the convection streamlines. The latitude distribution of potential along the 0600-1800 meridian and the distribution around the convection reversal boundary, assumed to be a circle of radius 12^c, are also shown. This formulation allows the relative shape of the convection cells to changed by changing these two distributions. Figure 2 shows two representations of the convection pattern that can be produced by changing these two distributions. They can be used to approximate empirical representations of the pattern for positive and negative values of IMF B_y respectively. We note that the changes in the shape of the pattern are obtained by moving the location of the zero potential line on the dawn-dusk meridian and by changing the local time distribution of the potential. Thus a more quantitative representation of the pattern is obtained by attempting to find the dependence that these attributes of the pattern have on the value of B_y.

This task was undertaken by utilizing the DE-2 data base of electrostatic potential distributions derived from each high latitude satellite pass (Hairston and Heelis, 1990). Fits to the data were performed to determine the location of the zero crossing for extreme values of positive and negative B_y. The results are shown in figure 3. Similarly the data can be examined for changes in the local time distribution of the potential around the convection reversal boundary (Lu et al., 1989). In addition to changes in the geometry of the convection cells as a function of the IMF B_y component, it is also found that the absolute value of the potential extrema on the boundary are dependent on this parameter. Figure

3
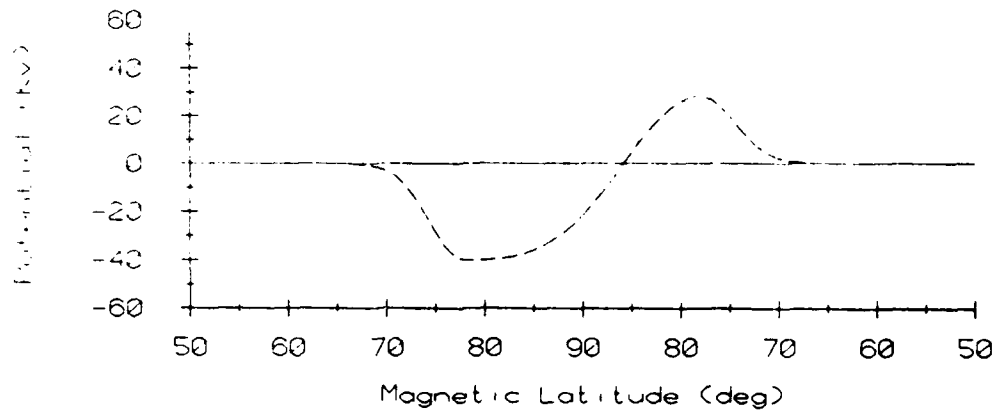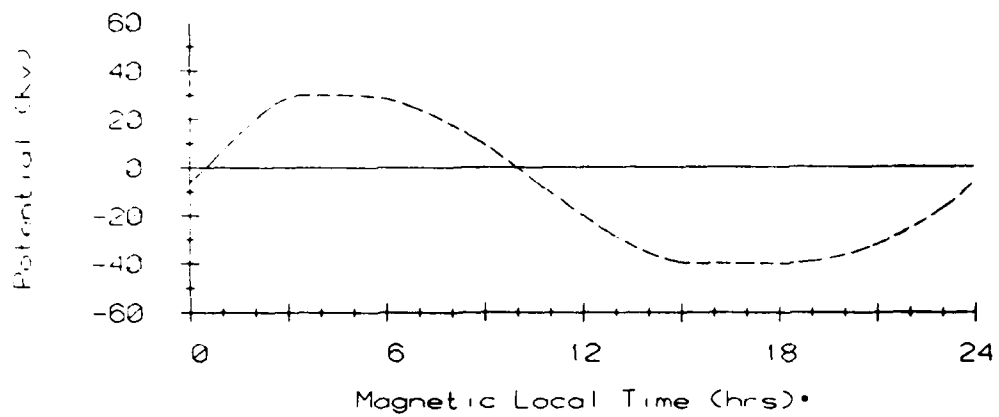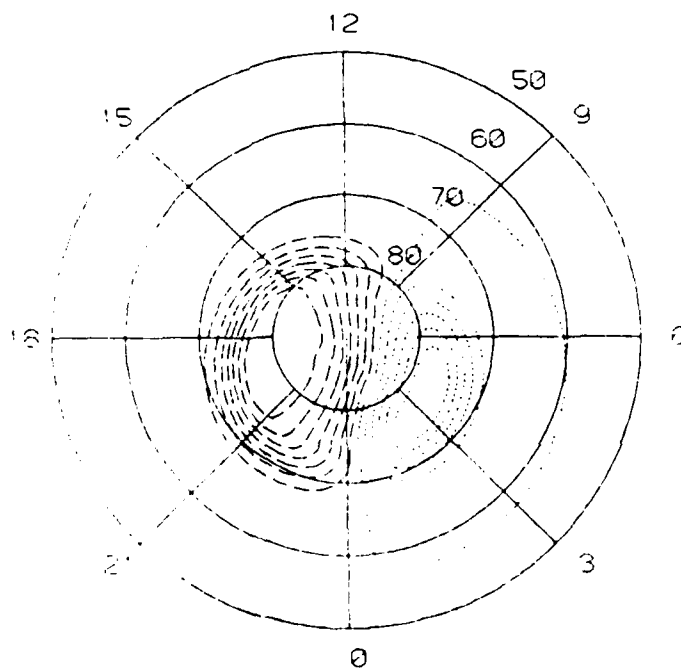
Figure 1. High Latitude Convection Pattern constructed from Latitude and Local Time distributions.

Psimax = 29 Kv   Psimin = 47 Kv

r = -5.0 B_y = -7
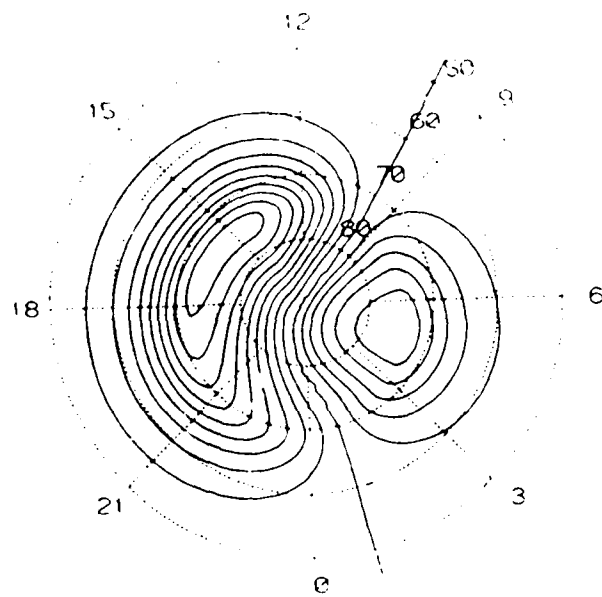
Psimax = 33 Kv   Psimin = 47 Kv

r = -5.0 B_y = +8
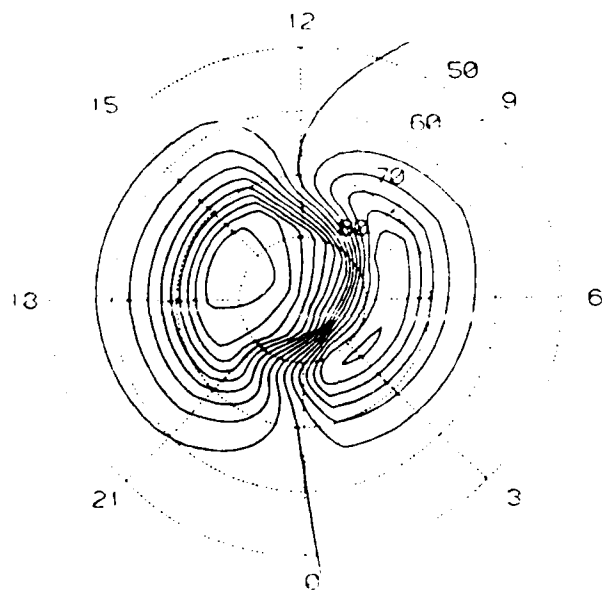
Figure 2. Representations of IMF B_y dependence of Convection Patterns.

5

4 shows that while a significant scatter in the data exists, a trend toward a dependence on B_y can easily be descerned. Finally it is found that a dependence of the radius of the convection reversal boundary on the potential drop across it (Siscoe, 1982) can be confirmed. With this cumulative information it is possible to insert analytical dependences on B_y into the expressions describing the convection pattern and thus produce a model that is dependent only on the IMF magnitude and direction. The model produced to describe the convection pattern for southward IMF has two important attributes. First it allows a global pattern to be produced that displays the first order dependences on the IMF shown by observations. Second, it allows fundemental parameters of the model, such as the location and magnitude of the potential extrema, which can be directly derived from satellite data, to be input directly to the model. The model is thus capable of producing a global representation of the convection pattern, that directly reproduces data from a given satellite pass. This exercise can be done quickly and easily for a single pass, and the task now remains to make it adaptive to multiple data sets. Several improvements to the model require further study of the data.

At present we have a good representation of the potential distribution as a function of latitude in the polar cap region. However, the local time distribution around the polar cap boundary, and the latitude distribution for latitudes below the polar cap boundary is not well quantified. Larger data bases are required to advance our understanding of the potential distribution around the boundary. However, the distribution at latitudes below the polar cap boundary requires us first to understand the geophysical variables that control its behavior. It is clear that during magnetic storms the magnetospheric field penetrates to lower latitudes in the ionosphere, but the temporal and spatial dependence of the phenomena is not well established. This present model is useful in determining the convective history of ionospheric plasma and the effects that changes in the pattern might have on observed plasma distributions at high latitudes.

2.1.2. Northward IMF

One of the products of the convection model development for southward IMF is the capability to produce a single convection cell of almost arbitrary shape and representing either clockwise or anticlockwise circulation. With this capability it is possible to begin development of a representation of the convection pattern for northward IMF by assuming that the pattern can be represented by four circulation cells with shapes, potential distributions and locations that depend on the magnitude and orientation of the IMF. The problem is approached in a similar manner as the case for southward IMF. First we establish the capability to reproduce various configurations of the convection pattern

6

Geometrical Asymmetry
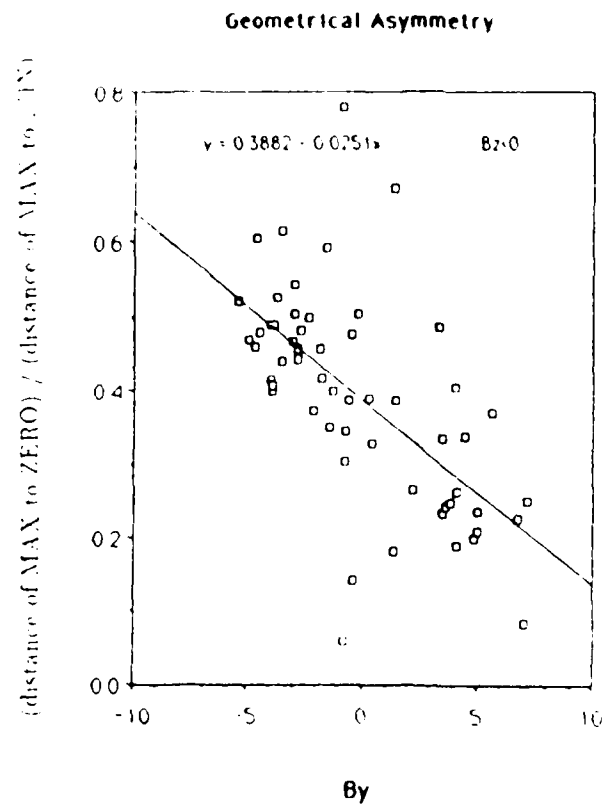
Figure 3. Dependence of geometrical asymmetry on IMF B_y.

Potential Asymmetry
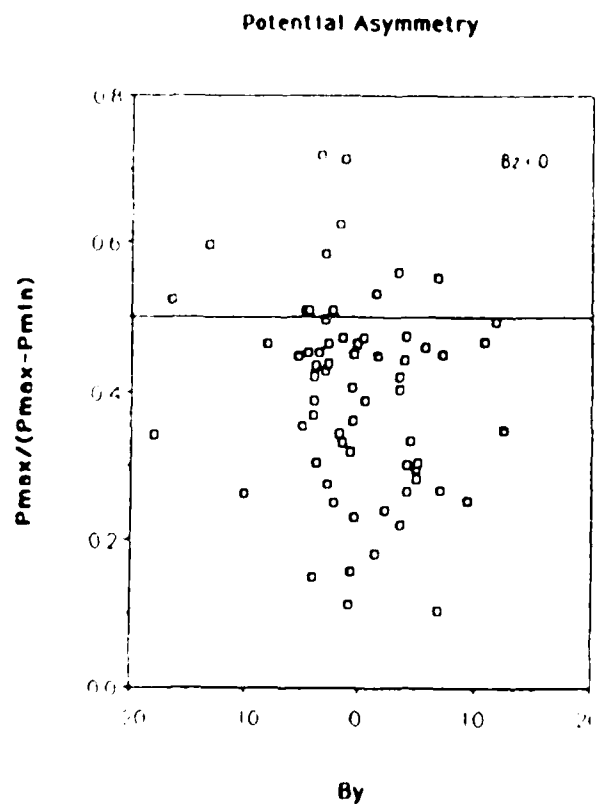
Figure 4. Dependence of Potential Asymmetry on IMF B_y.

7

Pmax = 15   Pmin = -15   Cint = 3

r = -4.0 $B_y = 0$

Pmax = 17   Pmin = -15   Cint = 3

r = -4.0 $B_y = 0$

Figure 5b.   Distorted two-cell convection pattern constructed for northward IMF.

Figure 5a.   Symmetric four-cell convection pattern constructed for northward IMF.

8

that have been put forward as representations for the flow during times of northward IMF. Then we determine the functional dependence of the controlling parameters on the IMF itself in order to arrive at a mathematical model. To date, the capability to reproduce many representations of the convection pattern has been established. Two extremes are a four-cell configuration put forward by a number of researchers (e.g. Burke et al., 1979, Maezawa, 1976) and a distorted two-cell pattern described by others (e.g. Heppner and Maynard, 1987). The development of the convection model for northward IMF assumes the existence of two drivers for the convective motion. One, that we will term "viscous interaction" is assumed to be derived from an electric field in the magnetospheric low-latitude boundary layer and is independent of the IMF but not of the solar wind speed and density. It produces an essentially symmetric two-cell convection pattern in the ionosphere, although as stated previously the dependences of the parameters in the model on external conditions has not yet been established. The second driver is derived from direct connection between the IMF lines in the magnetosheath with the geomagnetic field. This electric field and resulting convection pattern in the ionosphere is dependent on the IMF magnitude and orientation as well as the solar wind speed and density. It produces the familar assymetries in the convection pattern that have been studied for the case of southward IMF and in fact dominates the copnvection pattern during such periods. During northward IMF, however, the relative importance of these two drivers is not yet established and they combine to produce the variety of representations of the convection pattern that have been put forward in the literature. Figure 5 shows the capabilities of the model constructed in this way. The top panel shows a four-cell pattern obtained by adding the two cell convection patterns from each driver. Here we have assumed that both drivers produce symmetric patterns and thus, the resulting configuration is somewhat idealistic. Nevertheless, it allows us to establish variables such as the location of the convection pattern center and the radius of the convection reveral boundary for each driver, upon which a more realistic pattern may be developed. If these parameters are change and a less symmetric potential distribution for the "direct connection" driver is assumed, then the second panel shows quite convincingly how a distorted two- cell pattern may be formed. In addition to providing the capability to reproduce such convective configurations, the formulations currently being examined allow some insight into the evolution of the convection pattern from one state to another.

The availability of a convection model that allows the separate specification of flow patterns from two sources, raises the issue of their relative importance. Here we must recognize the difficulty in identifying the different drivers from ionospheric measurements, due to our inability to unequivocally determine the magnetic field topology. In an attempt

9

to shed some light on this topic we have undertaken a statistical study of the relationships between the boundaries in energetic particle precipitation regions and the boundaries in the convection pattern that mark reversals in the ion drift from sunward to antisunward (Coley et al., 1987). It is found that the identification of antisunward flow within a region of auroral precipitation is subject to some uncertainty because the region of overlap is generally very small. Thus the signature of "viscous interaction" in the ionosphere is very small. Either it is similarly small at the magnetopause, and can account for only a small fraction of the total cross polar cap potential, or the existence of parallel potential drops between the source and the ionosphere make it impossible to determine the relative importance from ionospheric measurements. Examination of the data shows that both sunward and antisunward convection on open field lines may be a relatively frequent occurence on the dayside of the dawn-dusk meridian, during times when the IMF B_y component is large. The data support the convective configuration proposed by Burch et al. (1985) in which both flow directions in the ionosphere are associated with flow in the lobes of the magnetotail. This "lobe cell" convection coexists with convection cells attributable to merging of the IMF with the Earth's closed field lines during times when the IMF is southward.

2.1.3. Temporal evolution of the Convection Pattern

In addition to attempts at constructing analytical expressions for the electrostatic potential distribution, the consequences of specifying the potential distribution around the convection reversal boundary and subsequently deriving the global potential from a solution of the Laplace equation have also been examined. A scenario is adopted for the solar wind/magnetosphere ionosphere coupling where closed magnetospheric flux tubes merge with the solar wind magnetic field. The resulting opened field lines convect across the polar cap ionosphere because of field line tension (Moses et. al., 1988,1989). In the model, the ionospheric plasma is treated as a two-dimensional fluid. An adiaroic boundary that approximates the convection reversal is placed in the fluid (Siscoe and Huang, 1985). Gaps in the adiaroic boundary allow flux to enter and leave and the boundary expands or contracts at a rate determined by the potential distribution along it and the net magnetic flux into or out of the region enclosed by the reversal boundary. The potential across the gap and the orientation of the gap is chosen to best reproduce the properties of individual data sets examined for different orientations of the IMF. It can be shown that by appropriately locating the position of multiple gaps in the adiaroic line, a good representation of the convection pattern can be obtained. Figure 6 shows one such example in which a dayside and a nightside gap are required but where the flux entering and leaving the polar cap is not equal. Thus the polar cap expands. During active periods intense electric fields form

10

premidnight. Also, on average the dawn convection cell spreads and the dusk cell retreats premidnight. The nightside gap forms along a meridian between 2200 and 0200 MLT. presumably when reconnection is occuring in the tail. Results indicate that the nightside gap forms after the expansion phase onset of a substorm and remains open through the recovery phase.

The usefulness of this description of the convection pattern lis in a deeper understanding of the response of the ionospheric convection pattern to changes in the IMF and in response to substorm activity. shape of the convection reversal boundary and the distribution of potential These findings should be incorporated into the next level of sophistication in analytical models.

2.2. Plasma Structures and convective flow

The appearance of plasma structures of varying scale sizes in the high latitude region. is of interest for many reasons. They are signatures of the temporal evolution of sources, sinks and transport of plasma in the region. They are also the seat of plasma density gradients subject to a variety of plasma instabilities. Here we confine our attention to the existence of so-called patches of ionization seen to convect antisunward across the polar cap during times of southward IMF [Weber et al., 1984]. These patches have scale sizes of 1000 km or so and measurements of the electron temperature inside them indicate that they are not the product of a local ionization source from precipitating particles. Other possible sources for pl.sma structure may be due to different residence times in regions where the plasma is produced. These regions lie in the auroral zone and the cusp. We have undertaken an initial study of the effects of a change in orientation of the convection pattern. due to changes in B_y. on the residence times of plasma packets in the auroral zone and cusp. Our hypothesis is that the boundary of a plasma enhancement in the polar cap marks a change in the convective history of the plasma. Initial studies [Anderson et. al., 1988]. indicate that this could indeed be the case. For a given location at very high latitudes. two effects must be taken account of when examining the total ion concentration. One is the radius of the polar cap itself, which is in turn related to the potential dop across it [Hairston and Heelis, 1990 . The other is the sign of B_y. which effects the orientationof the convection cells. Both these parameters can affect the past history of the plasma seen. for example at Thule. Figure 7 shows the predicted temporal evolution of the peak F-region density seen at Thule for two different configurations of the polar cap boundary. In one case (100 Kv x 15°) the plasma seen at thule in the late afternoon has convected through the evening side

11

DE-B ION DRIFT VELOCITIES

MLT V (LA)   NORTHERN HEMISPHERE
DAY 82054 UT17 05   ORBIT 3050

```
                     12

         15                     9



    18                             6


                 80
              70
                            
       21    60                  3
          50
                 0
```

1 km/sec

IONOSPHERIC CONVECTION FOR B

```
                    1200

       1500                      900



    1800            +            600



       2100                     300

                    2400
```
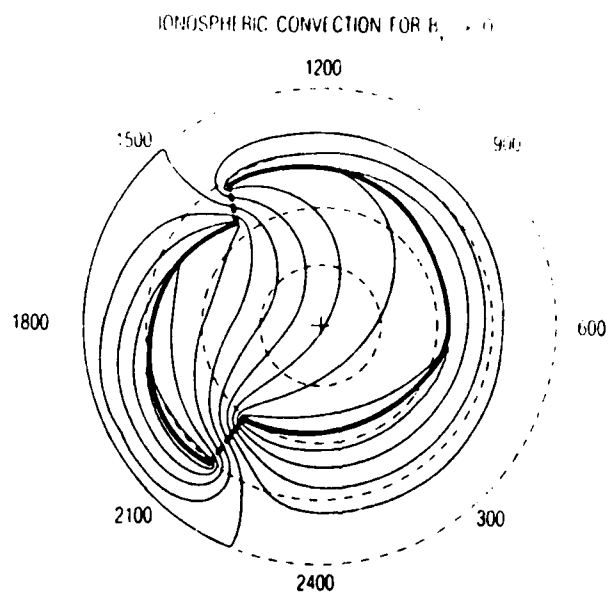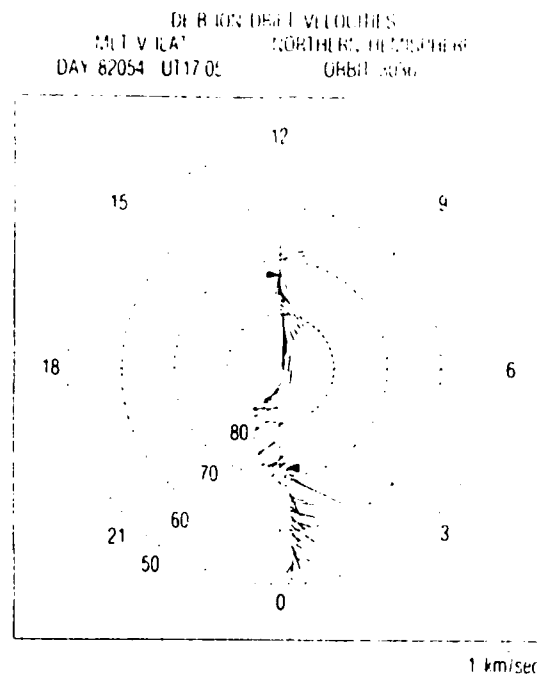
Figure 6. Representation of convective flow observed by DE-2 in terms of flow

gaps in an adiaroic boundary.

12

auroral zone and spent a long time in solar illumination compared to the other case (80 Kv x 12°) where at the same local time the plasma has convected from the morningside and spent little time in sunlight. It is clear that the different convective histories can produce the required differences in the total ion concentration. Further work is called for in this modelling effort to determine the effects of variations in the B_y component of the IMF and in the time scales for changes required to produce the plasma enhancements with spatial scales of a 1000 km or so.

2.3. Electrodynamics of Polar Cap Arcs.

In addition to the large scale convective features discussed previously, during periods of northward IMF, mesoscale features in the electric field and energetic particle environment pervade the entire high latitude region. On many occasions, these smaller scale features dominate the character of the plasma and are of considerable interest both electrodynamically and morphologically in that they are indicators of a vastly different configuration of the magnetosphere during times of northward IMF from that existing during southward IMF. We have undertaken a study of the mesoscale features existing during times of northward IMF, by using a variety of satellite and ground based instrumentation. Our first task was to establish the electrodynamic configuration of the structures and subsequently to understand how they are related to the larger scale features of the auroral zone.

During times of northward IMF the existence of sun-aligned arcs at very high latitudes is well established [Lassen and Danielsen et al., 1978.]. While observations from a satellite would suggest that the electric field configuration accompanying these arcs is somewhat turbulent and unorganized, a more complete examination from a variety of data sources serves to establish that this may not be the case [Carlson et al., 1988]. The uniquness of our approach lies in the combination of one dimensional data from a polar orbiting satellite and two-dimensional imaging from the ground using all-sky cameras. This allows a detailed examination of the electrodynamics of polar cap arcs and also examination of the extent to which the features manifest themselves as coherent entities. Such studies have shown that polar cap arcs are frequentlu elongated in the noon-midnight direction. While they may be only a few hundred kilometers in the dawn-dusk dimension they may extend across the entire polar cap in the noon-midnight direction, being many thousands of kilometers in extent. Detailed examination of the lectrodynamic properties of these arcs suggests that they may be associated with field-aligned potential differences. Figure 8 shows
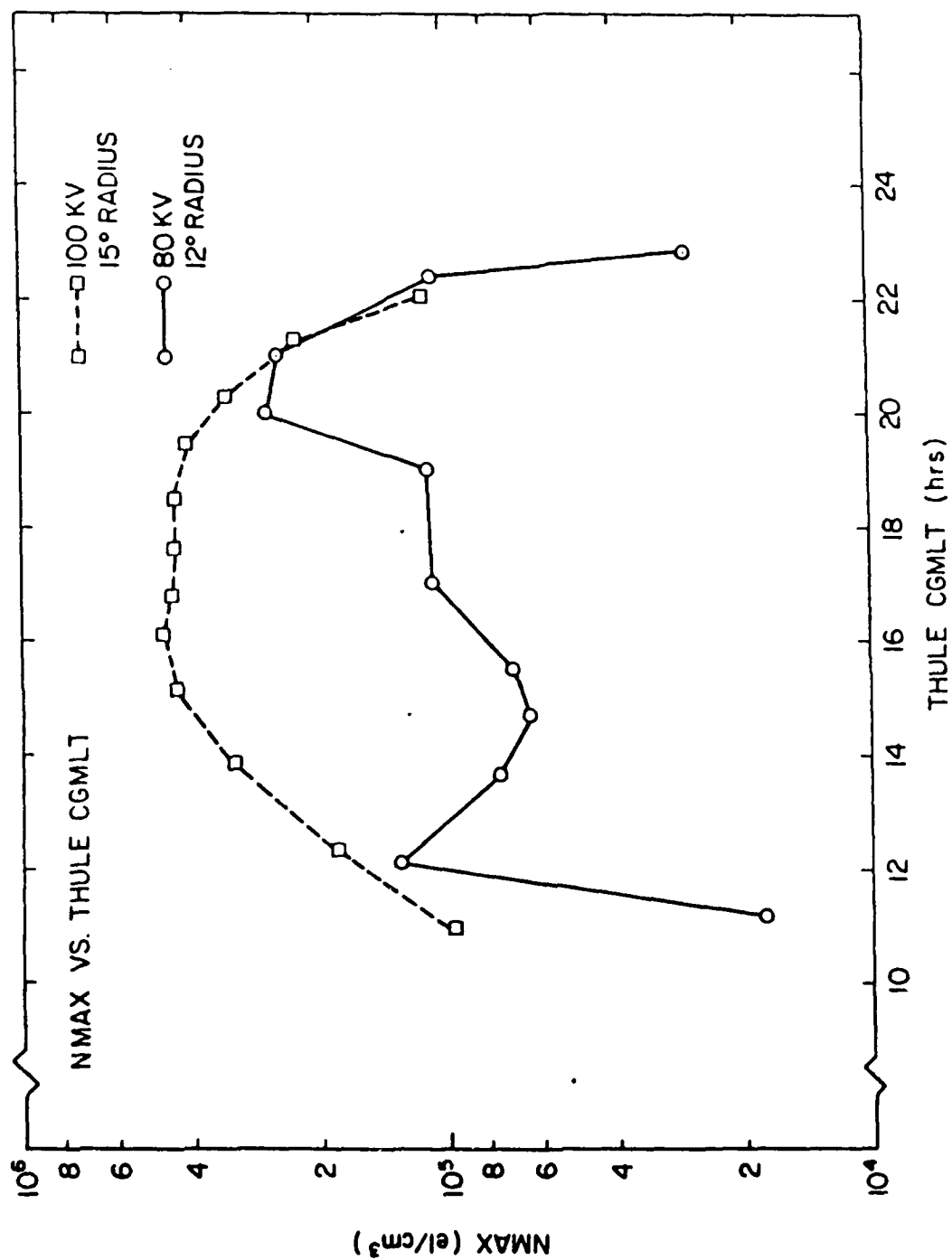
Figure 7. Calculated local time variation of F-peak concentration over Thule for differnt configurations of the convection pattern.
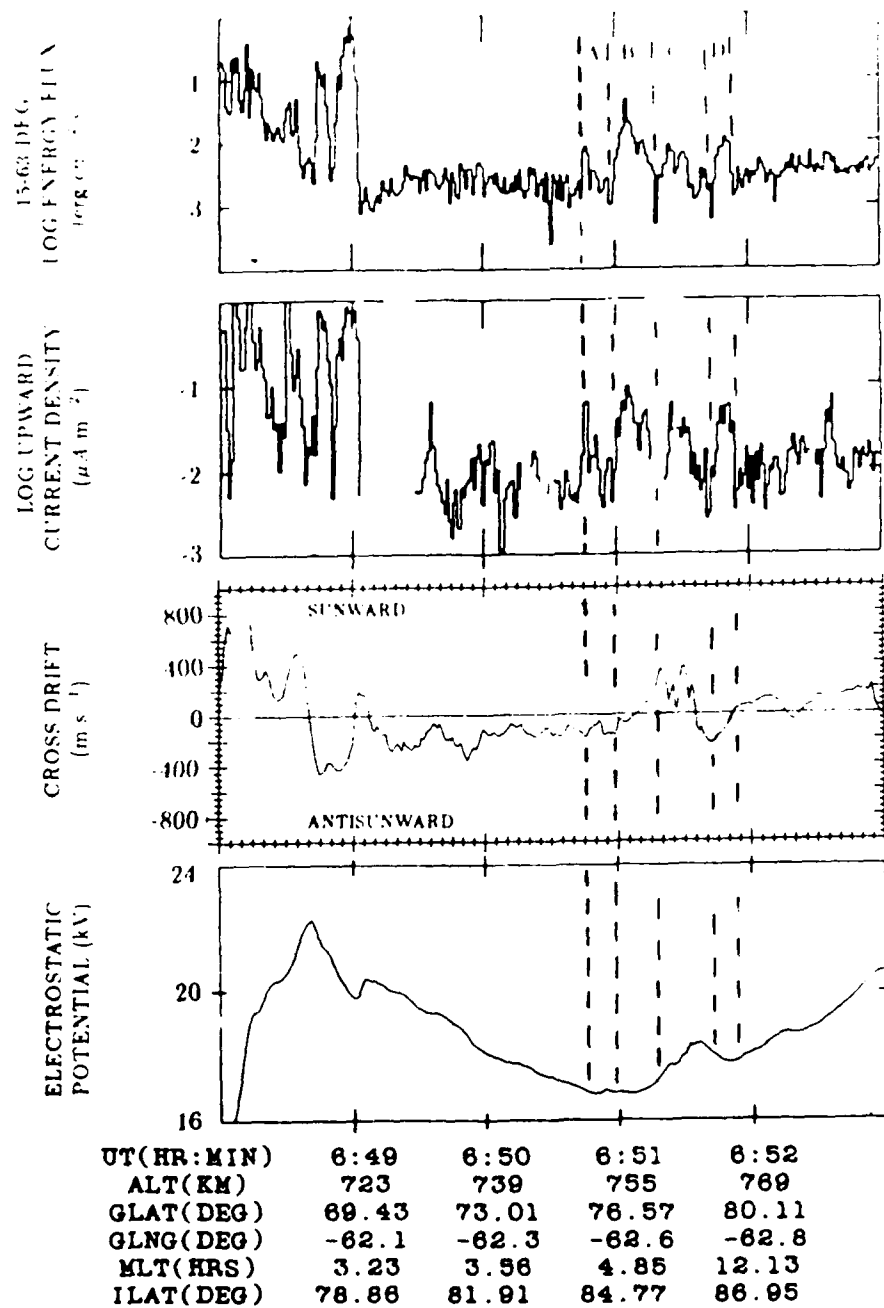
Figure 8. Electrodynamic properties observed by DE-2 during the crossing of four
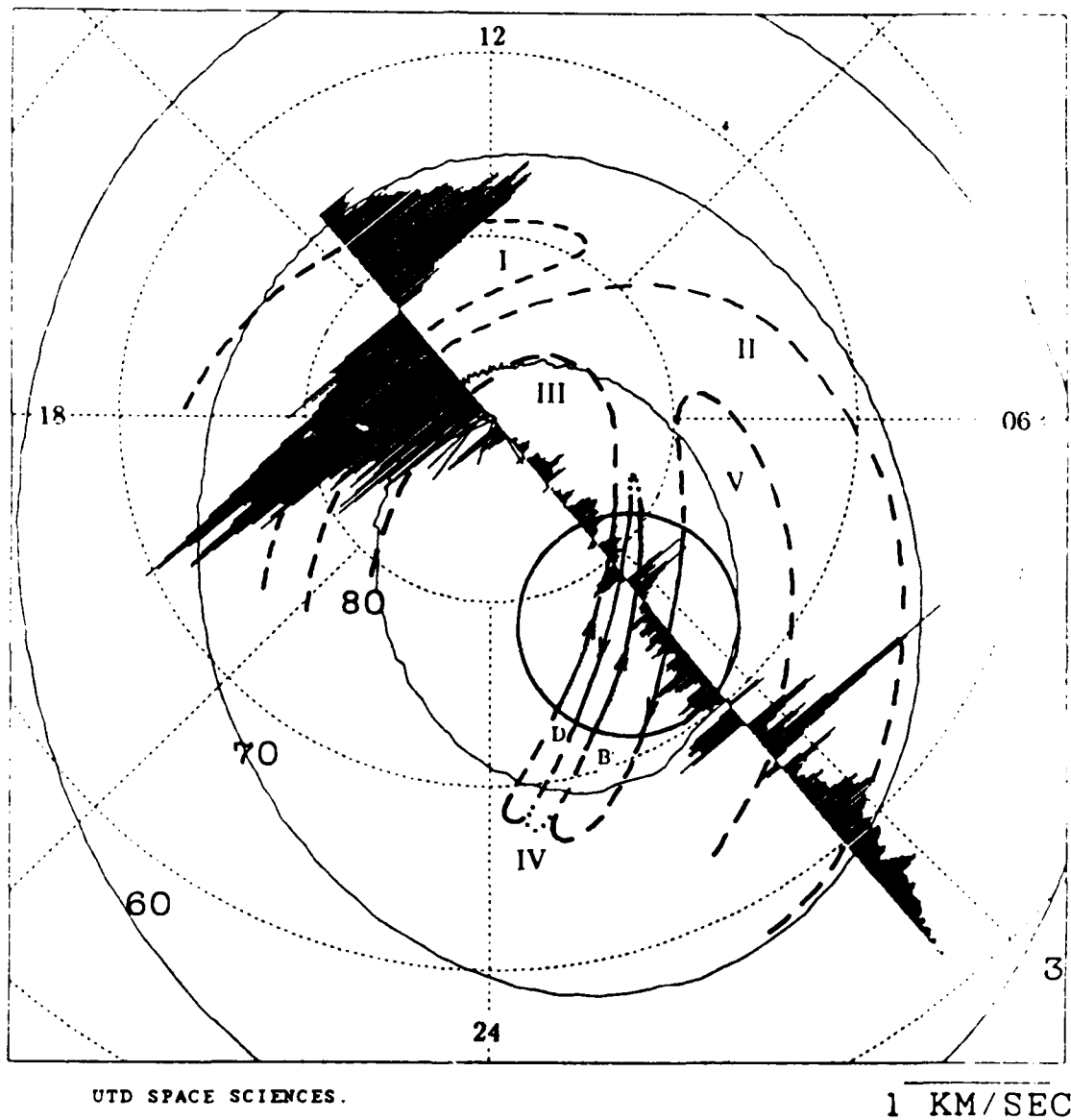
polar cap arcs.

Figure 9. Mososcale convection features identified with polar cap arcs and incorporated into a large scale global convection pattern.

the properties of four arcs, labelled A, B, C, and D. Each one is associated with a negative divergence in the electric field and in a uniform background conductivity would require an upward field-aligned current. Further examination of one of these arcs (B), shows that the precipitating electrons responsible for the emission are also carrying the required field-aligned current. Thus it appears that these arcs are electrodynamically similar to discrete arcs in the auroral zones 'Lyons, 1981', but they apparently involve much smaller field aligned potential drops, since precipitating electrons with energies greater that 1 keV are rarely seen. The coherent nature of these arcs implies that their electrodynamic properties are similarly preserved along them. If this is the case then it is possible to construct possible mesoscale convection features associated with them. One such example is shown in figure 9. Here it is suggested that small scale "finger-like" convection cells exist around each discrete feature. Detailed observations are still required to determine the nature of the connection between these mesoscale features and the larger scale convection features associated with plasma flow through the auroral zone. A recent opportunity to observe such a feature in the nightside auroral zone using radar and satellite imagery has shown that the arc may denote the division between antisunward flow that rotates clockwise into the polar cap antisunward flow that rotates anticlockwise into the auroral zone 'Nielsen et al., 1990.'. Previous observations of the theta aurora [Frank et al., 1986], have suggested that the sunward flowing plasma is associated with closed field lines that presumably map to the central plasma sheet. The implication is that antisunward flow is associated with open field lines on either side of the transpolar arc. We note that this need not be the case and that the antisunward flow on on one side of the arc may be associated with the low latitude boundary layer. Further work on the association between the global flow configuration and the appearance of sun-aligned arcs is necessary to advance our understanding of these features.

2.4. Electrical Coupling in Ionospheric Structures.

Studies of plasma structure in the high latitude ionosphere are complicated by the variety of structuring mechanisms and by the effects of transport, that can deliver structured plasma to places that are significant distances from the source. A previous section included some work and discussion about the formation of large scale structure from variations in the convective flow pattern. Here we are interested in the behavior of smaller scale structure as it is transported from its source. The electric field responsible for the transport will generally be of scale sizes larger than a few tens of kilometers and

originate from outside the ionosphere. However, the plasma structure itself will produce electric fields from the existence of pressure gradients, and these will exist at the variety of scale-sizes possessed by the structure. For scale sizes greater than about 5km the electric field associated with an isolated structure will map almost unattenuated along the magnetic field lines and its evolution will therefore depend on conditions existing at locations remote from the structure. For example, if an F-region structure convects over a highly conducting E-region, the electric field can be effectively shorted, thus increasing the rate at which this scale-size will decay if the E-region were not present. At scale sizes less than a few kilometers, this simple view of the processes acting to determine the evolution of F-region plasma structure is complicated by the fact that the magnetic field lines cannot be regarded as electric equipotentials. We have examined the processes involved utilizing two approaches. The first examines only the effects of the E-region on the temporal evolution of a plasma structure in the F-region. For this purpose we may assume that the F-region and E-region are slabs of plasma of some specified vertical extent, between which electric fields map and are unattenuated in so doing (Heelis et al., 1985). This simply means that an F-region structure will produce pressure gradient electric fields that may be partially shorted out by a conducting E-region. If the E-region is highly conducting then the F-region pressure gradient field will be shorted out and the structure will decay at a rate determined principally by the local perpendicular ion diffusion rate. If the E-region were a perfect insulator then the pressure gradient field would not be shorted and the plasma structure will decay at the local perpendicular electron diffusion rate. The real situation is, of course, in between these extremes, where the conducting properties of the E-region are important. However, as soon as the partially conducting E-region is considered, the effects of the E-region field on the local redistribution of plasma must be taken into account. This electric field tends to produce an image, in the E-region, of the F-region plasma structure.

The second approach considers in more detail the mapping properties of the electric field. In particular, it is important to understand that the electric field mapping process is scale size dependent (Heelis and Vickrey, 1990). Thus electric fields from F-region structures of small scale size (< 1km) may be quite large but not map effectively to a highly conducting E-region. Electric fields from larger scale features in the F-region, map effectively to the E-region, but the electric fields are of smaller magnitude. In order to understand all these effects it is necessary to consider the altitude distribution of the electric field and the plasma. With this consideration we see that a given altitude below the source region for the electric field will show a preferred scale size at which the compressional effects (and therefore image formation) are a maximum. Since the electric field is proportional to

18

the plasma pressure gradient, electric fields are largest for smallest scale sizes at the source. However the smaller scale sizes do not map effectively away from the source. Thus the electric field at any location will be a combination of the altitude mapping process and the scale size under consideration. At large scale sizes, the amplitude of image structure will increase with decreasing scale sizes for all source perturbations whose amplitudes decrease less rapidly than k^{-2}. The inclusion of the electric field mapping process simply enforces a decrease in the amplitude of image structure at large k for any amplitude distribution of the source. Thus a high frequency "roll-off" of the image spectrum willl always occur and will occur at smaller k values (larger scale-size) than predicted by a theory that does not include the electric field mapping properties.

3. Ionospheric Frictional Heating.

In addition to the importance in determining the convective history of the high latitude plasma and the response of the convection pattern to changes in the IMF, we are also interested in the effects of the plasma motion on its energy content. The large convective flow velocities seen at high latitudes, imply the existence of significant frictional heating, and in such areas, the plasma will expand, the plasma composition will change and the heat will be delivered to the neutral gas. In describing the effects of the plasma motion on the temperature of the gas it is important to distinguish between a heating rate determined from the product of the electric field and the height integrated Pedersen conductivity and the heating per particle determined from the local difference between the ion and neutral wind velocities. In order to understand the different implications of these two parameters we have undertaken a morphological study of the global distribution of the ion temperature and the ion velocity (Heelis and Coley, 1988). By examining the differences in the distributions of temperature and velocity we can ascertain the effects of local neutral winds in moderating or increasing the ion heating rate. By examining deifferences between the ion temperature distribution and the global frictional heating rate or $\Sigma_p E^2$, we can see the effects of the ion concentration on the ion temperature. Significant differences can be seen. Figure 10 serves to illustrate most of the features. The Joule heating rate is dependent on both the relative ion-neutral velocity and the total ion concentration. On the other hand, enhancements in the ion temperature depend only on the relative ion-neutral velocity. It is thus the heating rate per particle that is related to the ion temperature. Regions of large Joule heating rate produced by enhancements in the ion concentration will not necessary be accompanied by enhancements in the ion temperature. In the F-region,

19

this phenomenum manifests itself in the cusp region. In the dawnside F-region, a local maximum in the ion temperature is seen in the F-region while no such maximum exists in the heating rate. In this case, a maximum in the ion neutral velocity certainly does exist, but this is counteracted by a minimum in the total ion concentration. Thus the heating rate per particle is a maximum, while the total heating rate is not.
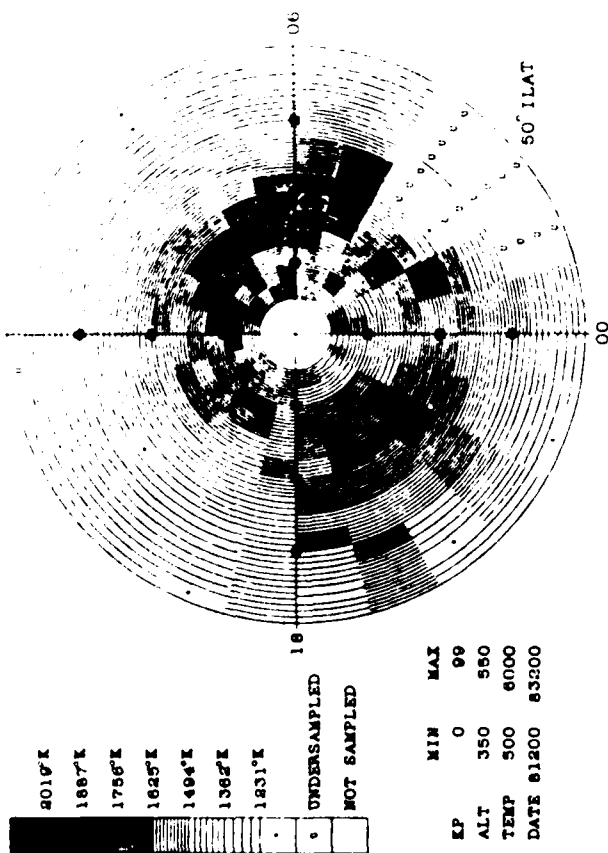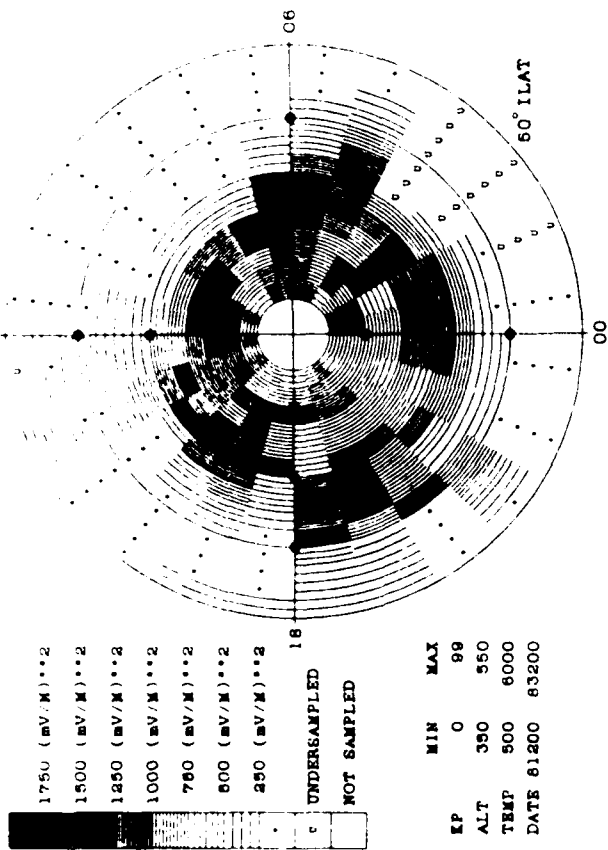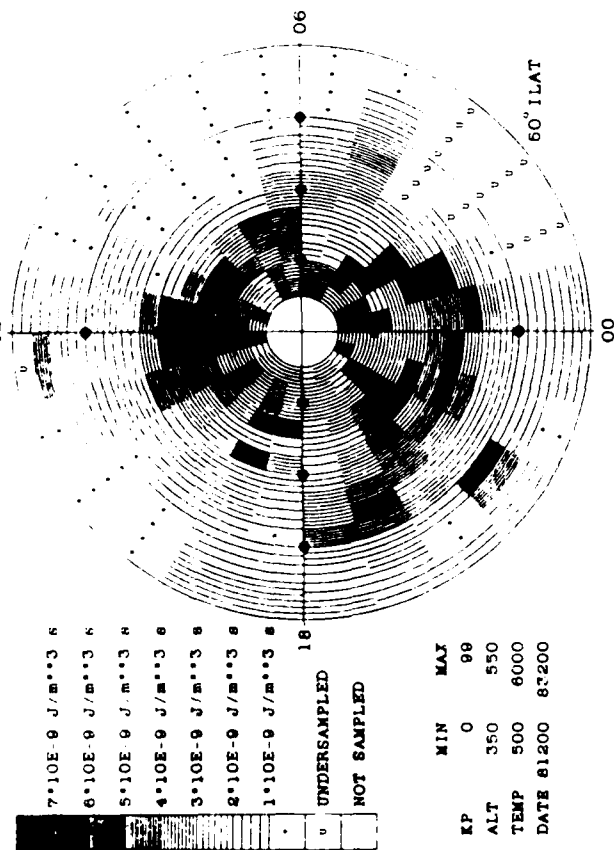
Figure 10. Global distributions of F-region ion (temperature, ion velocity and frictional heating rate determined from DE-2.

References

Anderson, D.N., J. Buchau, and R.A. Heelis, Origin of density enhancements in the winter polar cap ionosphere, *Radio Sci.*, *23*, 513, 1988.

Burch, J.L., P.H. Reiff, J.D. Menietti, R.A. Heelis, W.B. Hanson, S.D. Shawhan, E.G. Shelley, M. Sugiura, D.R. Weimer, and J.D. Winningham, IMF B_y-dependent plasma flow and Birkeland currents in the dayside magnetosphere, 1, Dynamics Explorer observations, *J. Geophys. Res.*, *90*, 1577-1593, 1985.

Burke, W.J., M.C. Kelley, R.C. Sagalyn, M. Smiddy, and S.T. Lai, Polar cap electric field structures with a northward interplanetary magnetic field, *Geophys. Res. Lett.*, *6*, 21, 1979.

Carlson, H.C., R.A. Heelis, E.J. Weber, and J.R. Sharber, Coherent mesoscale convection patterns during northward interplanetary magnetic field, *J. Geophys. Res.*, *93*, 14501-14514, 1988.

Coley, W.R., R.A. Heelis, W.B. Hanson, P.H. Reiff, J.R. Sharber, and J.D. Winningham, Ionospheric convection signatures and magnetic field topology, *J. Geophys. Res.*, *92*, 12352-12364, 1987.

Frank, L.A., J.D. Craven, D.A. Gurnett, S.D. Shawhan, D.R. Weimer, J.L. Burch, J.D. Winningham, C.R. Chappell, J.H. Waite, R.A. Heelis, N.C. Maynard, M. Sugiura, W.K. Peterson, and E.G. Shelley, The Theta Aurora, *J. Geophys. Res.*, *91*, 3177-3224, 1986.

Hairston, M.R., and R.A. Heelis, A model of the ionospheric convection pattern for southward IMF based on DE-2 observations, *J.Geophys. Res.*, in press, 1990.

Heelis, R.A., and W.R. Coley, Global and local Joule heating effects seen by DE-2, *J. Geophys. Res.*, *93*, 7551, 1988.

Heelis, R.A., J.F. Vickrey, and N.B. Walker, Electrical coupling effects on the temporal evolution of F-layer plasma structure, *J. Geophys. Res.*, *90*, 437, 1985.

Heelis, R.A., and J.F. Vickrey, Magnetic field-aligned coupling effects on ionospheric plasma structure, *J.Geophys. Res.*, in press, 1990.

Heppner, J.P., and N.C. Maynard, Empirical high latitude electric field models, *J. Geophys. Res.*, *92*, 4467-4489, 1987.

Lassen, K., and C. Danielson, Quiet time pattern of auroral arcs for different directions of the interplanetary magnetic field in the Y-Z plane, *J. Geophys. Res.*, *83*, 5277-5283, 1978.

Lockwood, M., and S.W.H. Cowley, Observations at the magnetopause and in the auroral ionosphere of momentum transfer from the solar wind, *Adv. Space Res.*, *8*, 281-299, 1988.

Lu, G, P.H. Reiff, M.R. Hairston, R.A. Heelis, and J.L. Karty, Distribution of convection

potential around the polar cap boundary as a function of the interplanetary magnetic field, *J.geophys. Res.*, *94*, 13447-13461, 1989.

Lyons, L.R. Discrete aurora as the direct result of an inferred high altitude generating potential distribution, *J. Geophys. Res.*, *86*, 1, 1981.

Maezawa, K., Magnetospheric convection induced by the positive and negative Z components of the interplanetary magnetic field: Quantitative analysis using polar cap magnetic records, *J. Geophys. Res.*,*81*, 2289-2303, 1976.

Moses, J.J., G.L. Siscoe, R.A. Heelis, and J.D. Winningham, A model for multiple throat structures in the polar cap flow entry region, *J. Geophys. Res.*, *93*, 5741-5759, 1988.

Moses, J.J., G.L. Siscoe, R.A. Heelis, and J.D. Winningham, Polar cap deflation during magnetospheric substorms, *J. Geophys. Res.*, *94*, 3785-3789, 1989.

Nielsen, E. J.D. Craven, L.A. Frank, and R.A. Heelis, Ionospheric flows associated with a transpolar arc, *J. Geophys Res.*, submitted, 1990.

Siscoe, G.L., and T.S. Huang, Polar cap infalation and deflation, *J. Geophys. Res.*, *90*, 543-547, 1985.

Siscoe, G.L., Polar cap size and potential: A predicted relationship, *Geophys. Res. Lett.*, *9*, 672-675, 1982.

Weber, E.J., J. Buchau, J.G. Moore, J.R. Sharber, R.C. Livingston, J.D. Winningham, and B.W. Reinisch, F-layer ionization patches in the polar cap, *J. Geophys. Res.*, *89*, 1683-1696, 1984.

4. Publications.

The previously described research effort has provided is the opportunity, not only to study and advance our understanding of the dynamics and composition of the high-latitude ionospheric plasma, but also to distribute the results to the community in publications. While this report attempts to summarize the findings of our work, it is more completely described in 9 publications that have appeared or will shortly appear in the literature. The following pages contain abstracts of preprints or reprints from the published papers:

Coley, W.R., R.A. Heelis, W.B. Hanson, P.H. Reiff, J.R. Sharber, and J.D. Winningham, Ionospheric convection signatures and magnetic field toplogy. *J. Geophys. Res.*, *92*, 12352-12364, 1987.

Heelis, R.A., and W.R. Coley, Global and local Joule heating effects seen by DE-2., *J. Geophys. Res.*, *93*, 7551, 1988.

Anderson, D.N., J. Buchau, and R.A. Heelis, Origin of density enhancements in the winter polar cap ionosphere. *Radio Sci.*, *23*, 513, 1988.

Moses, J.J., G.L. Siscoe, R.A. Heelis, and J.D. Winningham, A model for multiple throat structures in the polar cap flow entry region, *J. Geophys. Res.*, *93*, 5741-5759, 1988.

Carlson, H.C., R.A. Heelis, E.J. Weber, and J.R. Sharber, Coherent mesoscale convection patterns during northward interplanetary magnetic field, *J. Geophys. Res.*, *93*, 14501-14514, 1988.

Moses, J.J., G.L. Siscoe, R.A. Heelis, and J.D. Winningham, Polar cap deflation during magnetospheric substorms, *J. Geophys. Res.*, *94*, 3785-3789, 1989.

Hairston, M.R., and R.A. Heelis, A model of the ionospheric convection pattern for southward IMF based on DE-2 observations, *J.Geophys. Res.*, , in press, 1990.

Nielsen, E., J.D. Craven, L.A. Frank, and R.A. Heelis, Ionospheric flows associated with a transpolar arc, *J. Geophys Res.*, submitted, 1990.

Heelis, R.A., and J.F. Vickrey, Magnetic field-aligned coupling effects on ionospheric plasma structure., *J.Geophys. Res.*, in press, 1990.

Ionospheric Convection Signatures and Magnetic Field Topology

W. R. Coley, R. A. Heelis, and W. B. Hanson

Center for Space Sciences, University of Texas at Dallas, Richardson, Texas

P. H. Reiff

Center for Space Physics, Rice University, Houston, Texas

J. R. Sharber and J. D. Winningham

Southwest Research Institute, San Antonio, Texas

We present here a statistical study of signatures of the high-latitude ionospheric convection pattern and the simultaneously observed energetic electron precipitation. We most often find convection cells in which the sunward flowing region contains auroral particle precipitation but the antisunward flowing region does not. However, our observations also show the frequent occurrence of convection cells in which neither the antisunward nor the sunward flowing plasma region contains auroral particle precipitation. These findings may appear within the dawnside or duskside convection pattern and strongly suggest that such convection cells may be associated with open magnetic field lines that thread the magnetotail lobes. Examination of the interplanetary magnetic field (IMF) data shows that this "lobe cell" convection signature is most likely to be accompanied by the signature of dayside merging when the IMF has a significant y component but is directed southward. A lobe convection cell has a location and sense of circulation that are dependent on the sign of B_y. For the northern hemisphere, clockwise circulation displaced to the duskside appears roughly 35% of the time when B_y is positive, and anticlockwise circulation displaced to the dawnside appears when B_y is negative. The same circulation sense and location exist in the southern hemisphere for the opposite polarity of B_y. At times of northward IMF, the circulation within the polar cap can be at least partially on closed field lines and cannot be easily reconciled with merely a distortion of the standard "two-cell" convection pattern. The significance of these results to several models of the solar wind/magnetosphere interaction is discussed.

Global and Local Joule Heating Effects Seen by DE 2

R. A. Heelis and W. R. Coley

Center for Space Sciences, University of Texas at Dallas, Richardson

In the altitude region between 350 and 550 km, variations in the ion temperature principally reflect similar variations in the local frictional heating produced by a velocity difference between the ions and the neutrals. Here we show the distribution of the ion temperature in this altitude region and discuss its attributes in relation to previous work on local Joule heating rates. In addition to the ion temperature, instrumentation on the DE 2 satellite also provides a measure of the ion velocity vector representative of the total electric field. From this information we derive the local Joule heating rate. From an estimate of the height-integrated Pedersen conductivity it is also possible to estimate the global (height-integrated) Joule heating rate. Here we describe the differences and relationships between these various parameters.

Origin of density enhancements in the winter polar cap ionosphere

D. N. Anderson and J. Buchau

Air Force Geophysics Laboratory, Hanscom Air Force Base, Massachusetts

R. A. Heelis

University of Texas at Dallas, Richardson, Texas

Coherent and incoherent ground-based radar measurements of the winter polar cap ionosphere at Thule and Sondrestrom, Greenland have established the existence of "patches" of enhanced ionization which drift across the polar cap in an antisunward, noon-midnight direction. Associated with these patches is strong radio scintillation activity which severely disrupts ground-to-satellite communication systems and interferes with the operation of space surveillance radar at high latitudes. Several recent studies have shown that the source of enhanced ionization is the sunlit subcusp ionosphere rather than production by precipitating energetic particles. However, the question of what causes the patchiness has not been addressed. We study this problem by solving the time-dependent plasma continuity equation including production by solar ultraviolet radiation, loss through charge exchange, and transport by diffusion and convection $E \times B$ drifts. Time and spatially varying, horizontal $E \times B$ drift patterns are imposed, and subsequent ionospheric responses are calculated to determine how enhanced plasma densities in the dark polar cap could result from extended transit of relevant flux tubes through regions of significant solar production. This would occur south of the cusp prior to convection as patches across the polar cap. It is found that a density enhancement in N_{max} from 7×10^4 to 5×10^5 el cm^3 occurs at Thule when a time-varying convection pattern is included in the simulation. The patch of ionization is generated when an initial convection pattern characterized by an 80-kV cross-tail potential and a 12 polar cap radius is abruptly changed to a 100-kV cross-tail potential and a 15 polar cap radius. The horizontal extent of the patch is related to the length of time the new convection pattern remains "turned on."

A Model for Multiple Throat Structures in the Polar Cap Flow Entry Region

J. J. MOSES,[1] G. L. SISCOE,[2] R. A. HEELIS,[3] AND J. D. WINNINGHAM[4]

A two-dimensional ionospheric convection model has been developed to produce convection patterns for southward interplanetary magnetic field (IMF) and a positive or negative IMF y component. The model consists of a movable, shear convection reversal boundary with a gap in it where flux enters the polar cap. The sign of IMF B_y determines the dayside gap geometry. We use this simple model to simulate measured ionospheric flows from the DE 2 satellite. Roughly 35% of DE 2 passes that cross the dayside between 0800 and 1400 hours MLT cannot be modeled with a single narrow flow entry region. By comparing model calculations and the measured ion flows, we show that the dayside flow entry region to the polar cap typically spans several hours in local time. The electric field can concentrate along portions of the polar cap entrance and weaken between the concentrated regions, thus forming multiple "throats."

COHERENT MESOSCALE CONVECTION PATTERNS DURING NORTHWARD INTERPLANETARY MAGNETIC FIELD

H. C. Carlson,[1] R. A. Heelis,[2] E. J. Weber,[1] and J. R. Sharber[3]

Abstract. All-sky imaging photometer (ASIP) and coincident DE 2 satellite plasma drift and particle data have been combined to study polar ionospheric convection in the presence of subvisual intensity, soft-particle excited (F region), 6300-Å, Sun-aligned polar cap arcs. Coincident DE-B drift meter data identify these arcs electrodynamically as lines of negative electric field divergence. Based on conductivities, derived from the DE-B (low-altitude plasma instrument) measured particle fluxes, and the measured electric field gradients, the divergence of horizontal current across these particle impact excited arcs is in good quantitative agreement with upward Birkeland currents carried by the measured particle fluxes. Although velocity structure can be found without arcs, given the ASIP identified condition of stable weak (hundreds of rayleighs) 6300-Å Sun-aligned arcs in the polar cap, electric field negative divergence is consistently found. These arcs (of the order of 100 km in width) are found by ASIPs in the polar cap about half the time under $B_z > 0$ interplanetary magnetic field conditions. They are regularly seen by ASIP data to extend 1000 to over 2000 km in the sunward direction, and to persist in time often for over an hour. We are thus led to conclude that velocity gradients of this noon-midnight elongated scale are typical of $B_z > 0$ conditions. We further conclude that combined polar ASIP images and electrostatic potentials calculated along transpolar satellite tracks offer a valuable diagnostic for polar ionospheric convection studies under $B_z > 0$ conditions. The ASIP time continuous two dimensionality and the satellite equipotential scaling allow individual "snapshots" of these polar convection boundaries. Application here demonstrates highly anisotropic temporally stable convection with greater order than has previously been suspected.

Polar Cap Deflation During Magnetospheric Substorms

J. J. Moses,[1] G. L. Siscoe,[2] R. A. Heelis,[3] and J. D. Winningham[4]

The expanding-contracting polar cap model has been used to simulate DE 2 ion drift data during substorms as determined using the AL index. Of the 39 cases modeled, 57% required the opening of a nightside gap which maps to where reconnection occurs in the tail; 75% of the 16 recovery phase cases required a nightside gap while only 29% of the 17 expansion phase cases required a nightside gap. On the basis of this result, we conclude the following. If a nightside gap implies tail reconnection, then reconnection probably occurs after expansion phase onset and continues throughout most of the recovery phase of a substorm.

27

Model of the High-Latitude Ionospheric Convection Pattern During Southward Interplanetary Magnetic Field Using DE 2 Data

M. R. Hairston and R. A. Heelis

Center for Space Sciences, University of Texas at Dallas, Richardson

Data from the polar-orbiting satellite DE 2 are used to calculate one-dimensional electrostatic potential distributions across the polar cap region. Using passes that lie within ± 3 hours MLT of the dawn-dusk line, various parameters of the polar potential distribution (location and magnitude of the maxima and minima, location of the zero potential point, etc.) are analyzed in relation to each other and to the interplanetary magnetic field (IMF). The resulting dependences are used to derive a two-dimensional model of the distribution of the electrostatic potential in the high-latitude ionosphere during times of southward IMF. This model can be generated using as inputs either the ionospheric potential parameters or, based on the relationships analyzed here, the IMF conditions. The capabilities of the resulting mathematical model are illustrated, and the importance of retaining a flexibility in the model to accommodate individual observations is emphasized.

Ionospheric Flows Associated With a Transpolar Arc

by

E. Nielsen[1], J.D. Craven[2], L.A. Frank[2] and R.A. Heelis[3]

[1] Max-Planck-Institut für Aeronomie,
Katlenburg-Lindau, FRG

[2] Department of Physics and Astronomy,
University of Iowa, Iowa City, Iowa, 52242 USA

[3] University of Texas at Dallas, Richardson, Texas 75080 USA

Abstract

A theta aurora is observed in the northern hemisphere on 21 January 1982 using the auroral imaging instrumentation on board the DE-1 spacecraft. The period of observations is from 1807 to 2121 UT. The transpolar arc is observed to advanced toward the dusk sector, in the direction of the interplanetary magnetic field By component. Coincidentally, the intersection between the arc and the auroral oval near local midnight passes through the field-of-view of the STARE coherent radar system, thereby providing the opportunity for measurements of the spatial pattern of ionospheric electron drift velocities. The convection flow in the arc is directed toward the nightside auroral oval, where it divides into westward- and eastward-directed flows (eastward and westward electrojets). Sunward flows are not observed along the transpolar arc near midnight. The overall flow pattern is identical to that expected at the Harang discontinuity. Two traversals of the auroral oval and polar cap with DE 2 demonstrate that, as expected, transitions from antisunward to sunward flow are associated with the dayside of the transpolar arc. The evolution of the arc and its convective features observed simultaneously on both the dayside and the nightside allow a more complete description of its global configuration than has been made previously.

Magnetic Field-Aligned Coupling Effects on Ionospheric Plasma Structure

R. A. Heelis

The University of Texas at Dallas

J. F. Vickrey

SRI International

ABSTRACT

A mathematical description of the electrical coupling and dynamics of plasma structure in the E and F regions is presented. The scale size dependence of electric field coupling along the magnetic field is examined for a realistic background ionosphere and atmosphere. It is shown that, while normalized potentials map reciprocally between two altitudes, the potential disturbance caused by a fixed amplitude plasma density perturbation does not. The magnitude of the electrostatic potential created by structured ionization is also shown to be strongly dependent on the altitude of the structure.

The existence of plasma density structure at some altitude induces structure at other altitudes along the magnetic field in a scale size selective way. The early evolution of an F region structure that is initially confined in altitude is dominated by parallel diffusion. Low altitude image structure growth imposed by electrostatic fields mapped from the source is also very rapid; significant image amplitudes are reached in a matter of seconds. The altitude distribution of the evolving structure is strongly dependent on the scale size.

At E layer altitudes, where the Pedersen mobility is high and parallel diffusion relatively slow, a preferential scale-size for image structure is apparent for typical F region source spectra. This preferred scale size becomes smaller with increasing height. Above about 200 km altitude, however, parallel diffusion becomes increasingly important with height in determining the altitude and scale size distribution of structure resulting from a source at higher altitudes. The parallel diffusive flux can be modified by the existence of local plasma structure perpendicular to the magnetic field.